Severe Great Lakes Ice Cover in Winter 2008/09: Contribution of +AO and La Nina

Jia Wang[1], Xuezhi Bai[2], George Leshkevich[1], Marie Colton[1], Anne Clites[1] and Brent Lofgren[1]

[1]NOAA, Great Lakes Environmental Research Laboratory, Ann Arbor, MI
[2]Cooperative Institute for Limnology and Ecosystems Research, Ann Arbor, MI

Abstract

After nearly a decade of little ice cover, the Great Lakes experienced extensive ice cover during the 2008/09 winter, similar to the amount of ice formation during the 2002/03 winter. The bi-weekly ice area during the 2008/09 winter reached 75,010 km^2 in Lake Superior on March 2, 2009, nearly twice the maximum climatology (~40,000 km^2). The maximum ice area for all five Great Lakes during the 2008/09 winter was 166,380 km^2, which is comparable to the amount during the last severe winter of 2002/03 (166,423 km^2) although smaller than the previous severe winters of 1976/77 (201,655 km^2), 1978/79 (197,853 km^2), 1993/94 (189,940 km^2), and 1995/96 (184,505 km^2). The causal mechanism of the severe ice cover was the combined effects of an unusual positive Arctic Oscillation (AO) and a La Nina phase of El Nino and Southern Oscillation (ENSO) in the Pacific, leading to a negative surface air temperature (SAT) anomaly of ~ -2 to -4 ^{o}C over the Great Lakes. At the same time, the strong positive AO pattern also caused a warming in the Barents Sea (~ +10 ^{o}C) and the Arctic Ocean (~ +6 ^{o}C). The La Nina-derived weakened Aleutian Low caused a cooling in the Bering Sea, leading to a cold year in the northern North Pacific Ocean.

Motivation

The Laurentian Great Lakes, located in the mid-latitudes of eastern North America, contain about 95% of the U.S. and 20% of the world's fresh surface water supply. Nearly one-eighth of the population of the U.S. and one-third of the population of Canada live within their drainage basins. The ice cover that forms on the Great Lakes each winter and its year-to-year variability affects the regional economy (Niimi 1982), abiotic environment, the lake's ecosystems (Vanderploeg et al. 1992) and summer hypoxia, lake-effect snow inland, water balance, and water level variability (Assel et al. 2004). From the late 1990s to the early 2000s, lake ice cover was much less than normal, which enhanced evaporation and led to a significant water level drop of as much as 1-1.3 m. Lower water levels have a significant impact on the Great Lakes economy. For example, over 200 million tons of cargo are shipped every year through the Great Lakes. Since 1998 when water levels took a severe drop, commercial ships were forced to light-load their vessels. For every inch of clearance that these ocean-going vessels lost due to low water levels, each ship lost \$11,000-\$22,000 in profits. Lake ice loss can cause other problems, including the destruction of the eggs of fall-spawning fish by winter waves, erosion of coastal areas unprotected by shore ice, and safety in winter recreation on the lakes such as snowmobiling or ice fishing.

Atmospheric Data

Atmospheric data: NCEP

Lake ice data: Satellite measurements

Satellite Measurements

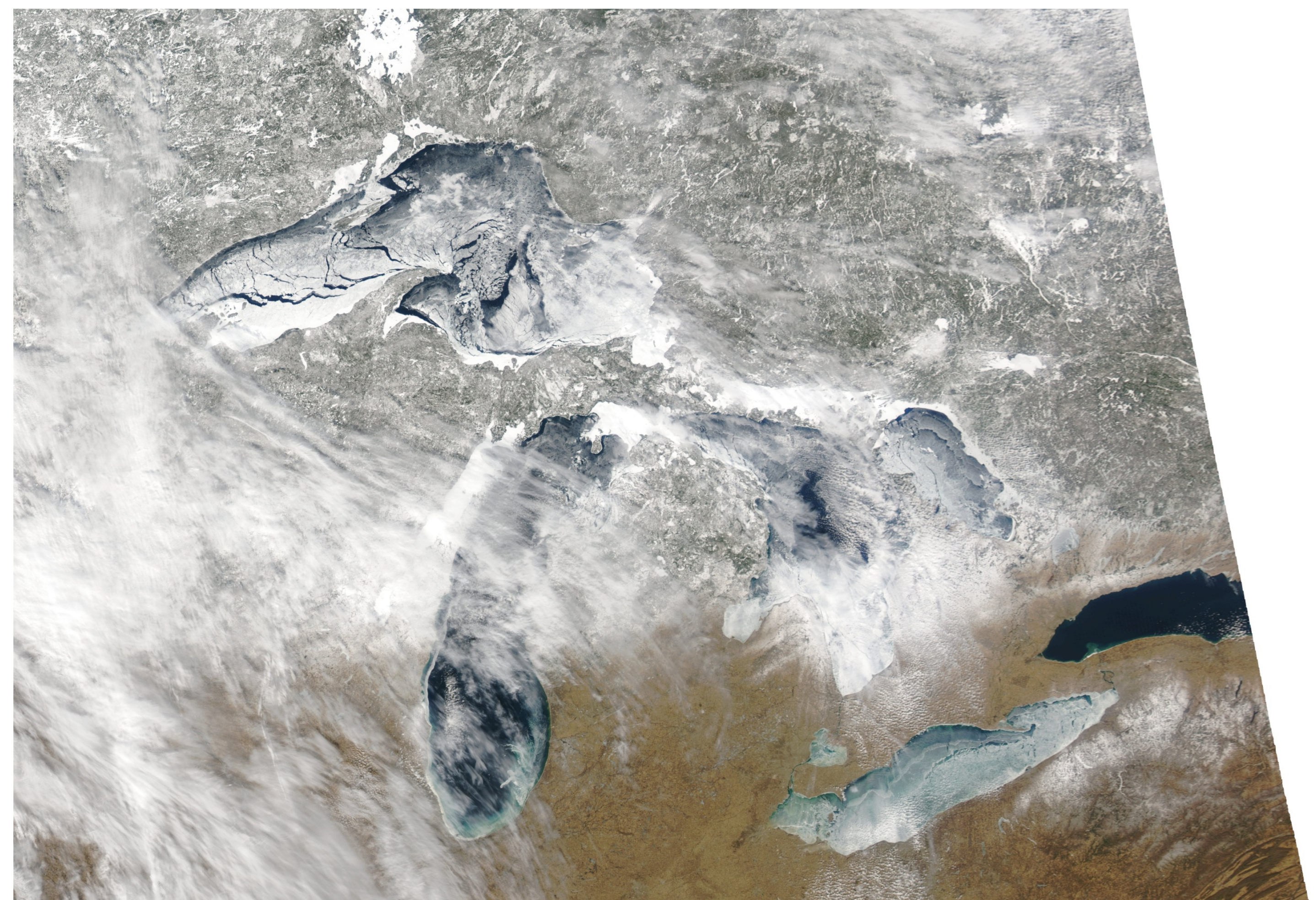

Figure 1. Maximum ice extent in the Great Lakes, as measured by MODIS on March 3, 2009.

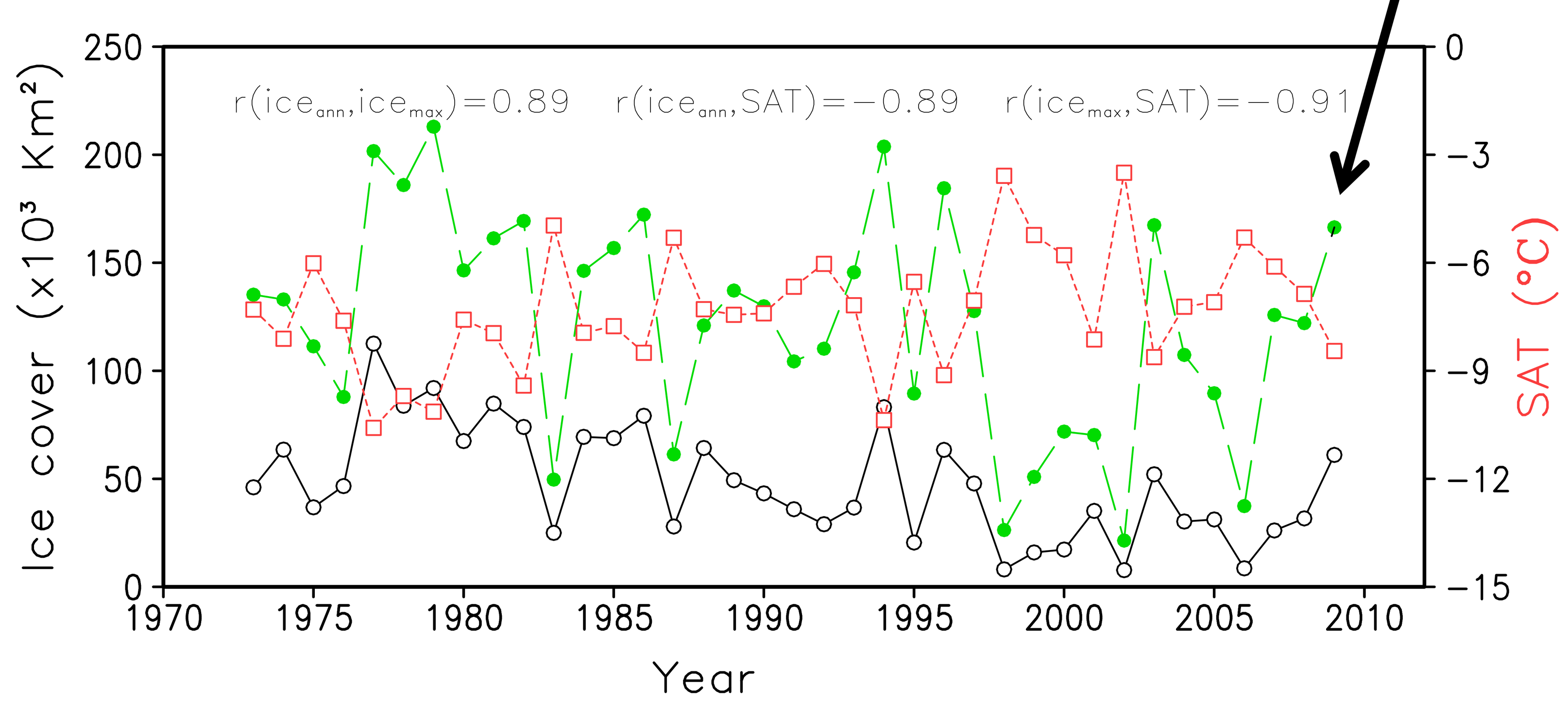

Figure 2. Time series of maximum ice area (dotted-green), annual averaged ice area (solid-black), and basin averaged SAT (dashed-red). The zero-lag correlations between the annual mean and maximum ice areas (r=0.89), between annual mean ice area and SAT (r=-0.89), and between annual maximum ice area and SAT (r=-0.91) are also shown.

Phenomenon

On March 2-3, 2009, Lake Superior was nearly completely ice covered, as were Lake Huron, Lake St. Clair, and Lake Erie (Fig. 1a). Even in northern Lake Michigan, there was severe ice cover. This severe ice event occurred after a decade-long low stand from 1997/98-2007/08, indicating a drastic change in the climate pattern in the Great Lakes region. The maximum ice area on March 2, 2009 for all five Great Lakes totaled 166,380 km^2 , comparable to the previous severe winters in 1976/77 to 1978/79, 1981/82, 1982/83, 1985/86, 1993/94, 1995/96, and 2002/03. The recovery of severe ice cover inhibited surface water evaporation during the 2008/09 winter, contributing to the observed higher water levels during the summer of 2009 compared with 2008. This drastic change in lake ice cover implies a significant natural variability caused by the hemispheric teleconnection climate pattern rather than a simple downward trend attributed to anthropogenic climate warming. Previous studies show that Great Lakes ice cover had a significant downward trend of ~ -1%/year for the period 1972/73-2000/2001. Nevertheless, considering the entire period 1972/73 to 2008/09, the downward trend disappears or even reverses. This indicates that 1) the natural variability dominates Great Lakes ice cover, and 2) since a trend is calculated from a specific period of time, it is only valid for the specific period.

Climate Forcing: +AO and La Nina

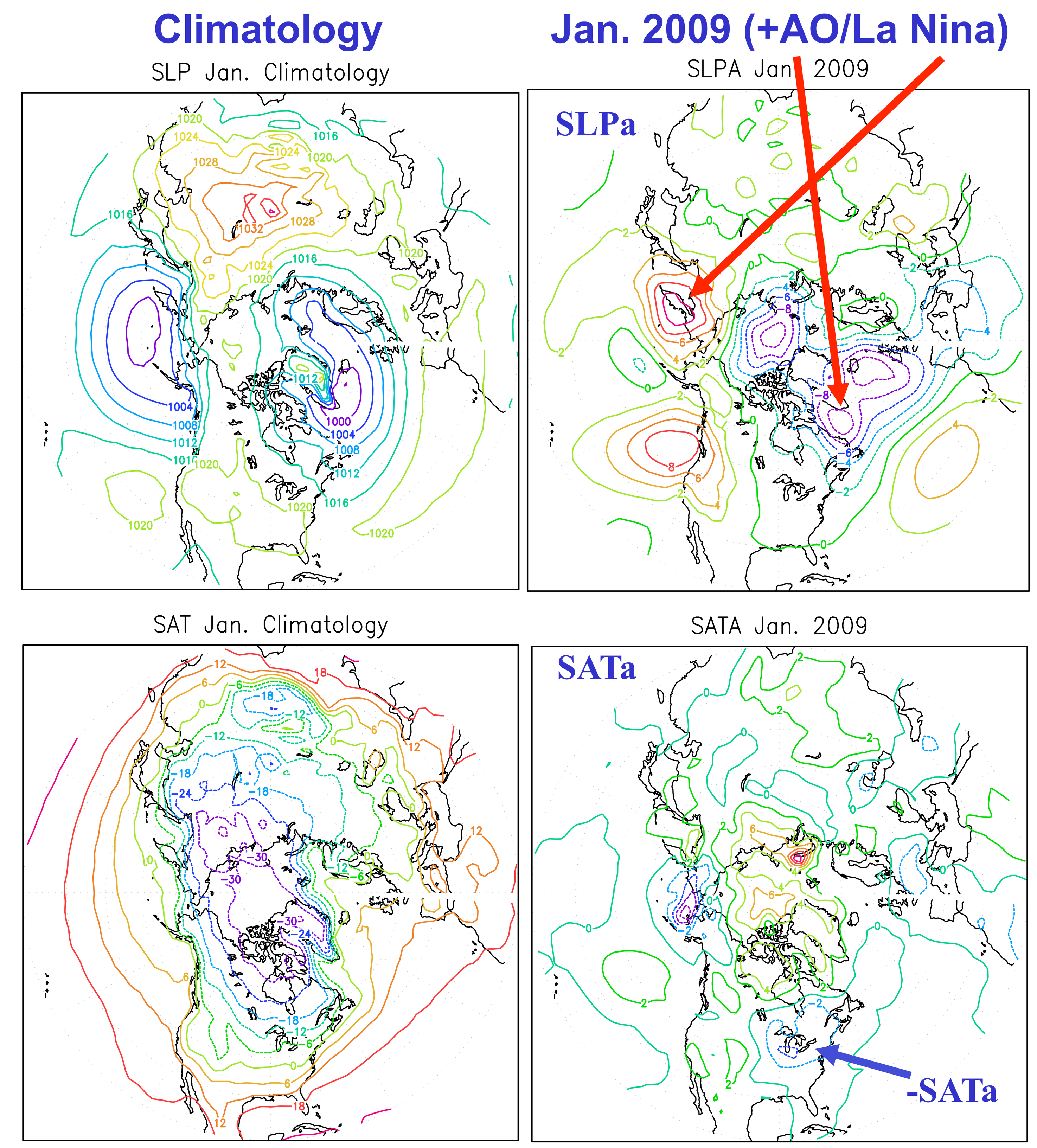

Figure 3. Climatology of SLP and SAT (left column) and SLP anomaly (SAPa) and SAT anomaly (SATa) (right column). The Great Lakes area was covered by a large negative anomaly of 2-4 degrees Celsius, due to an unusual +AO and La Nina event.

Conclusion

The severe ice season in winter 2008-2009 is due to the combined effects of both an anomalous AO episode and a persistent La Nina event, which belong to natural climate variability. This extreme, contradicting +AO event caused a cooling in the Great Lakes region, in phase with a cooling event caused by the La Nina event. This led to the extreme ice cover in the Great Lakes.

Given the complexity of the interaction between the AO and ENSO in the Great Lakes region, case studies of extreme events in lake ice cover should be addressed to better understand its year-to-year variability driven by natural climate patterns, in addition to the generalized statistical hindcast and forecast models based on climate pattern (teleconnection) indices (Assel and Rodionov 1998; Bai et al. 2010). A lack of numerical ice forecast models has hindered understanding of lake ice variability in response to both anthropogenic and natural climate forcing. Because the complexity of the interaction between AO and ENSO makes prediction of Great Lakes ice less reliable on the interannual time scale, the development of regional Great Lakes ice forecast models should be a high priority in order to further understand the impacts of global and regional climate on lake ice and other subsystems.